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(54) **SYSTEM AND METHOD FOR DETECTING AND SUPPRESSING ARC FORMATION DURING AN ELECTROSURGICAL PROCEDURE**

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(57) **ABSTRACT**

A method for suppressing arc formation during an electrosurgical tissue treatment procedure includes the steps of supplying pulsed current from an energy source to tissue and measuring the pulsed current supplied from the energy source. The method also includes the steps of comparing an instantaneous measured pulse to a predetermined threshold and controlling the pulsed current supplied from the energy source based on the comparison between the instantaneous measured pulse and the predetermined threshold.

**13 Claims, 4 Drawing Sheets**
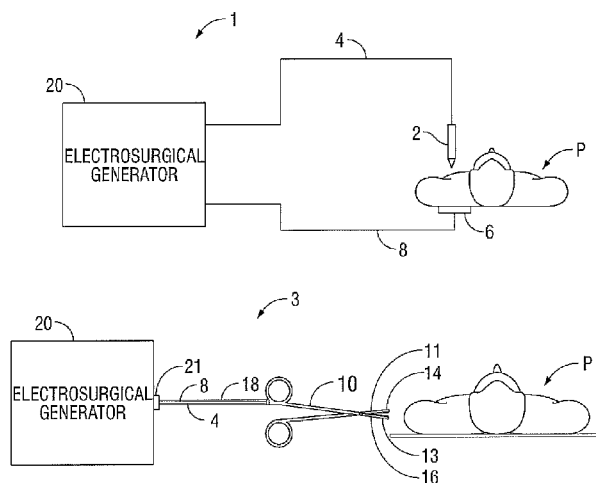
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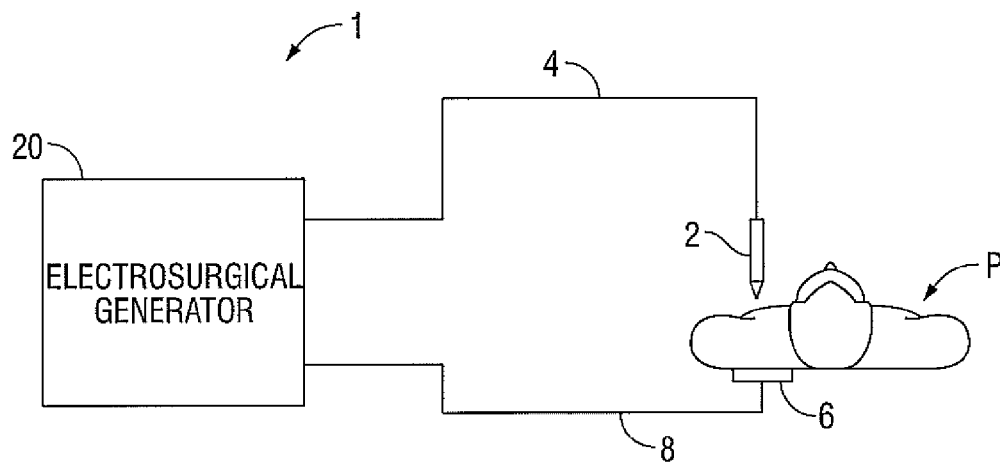International Search Report PCT/US09/46870 dated Jul. 21, 2009.
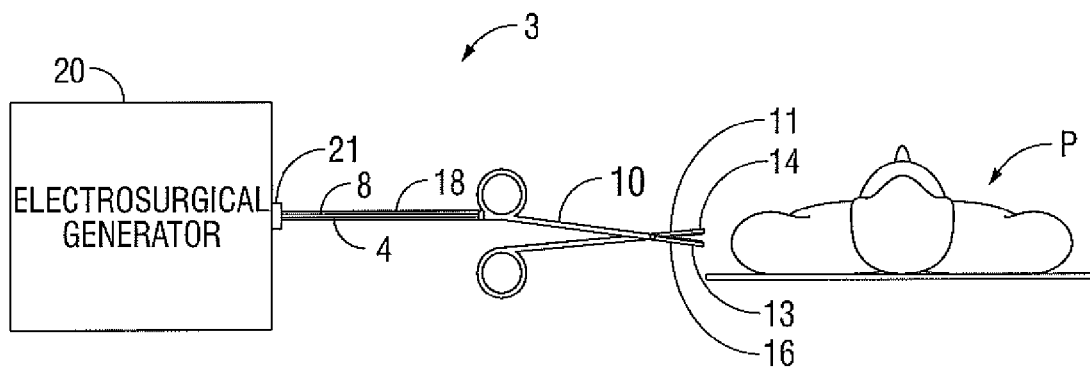
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**FIG. 1A**



**FIG. 1B**
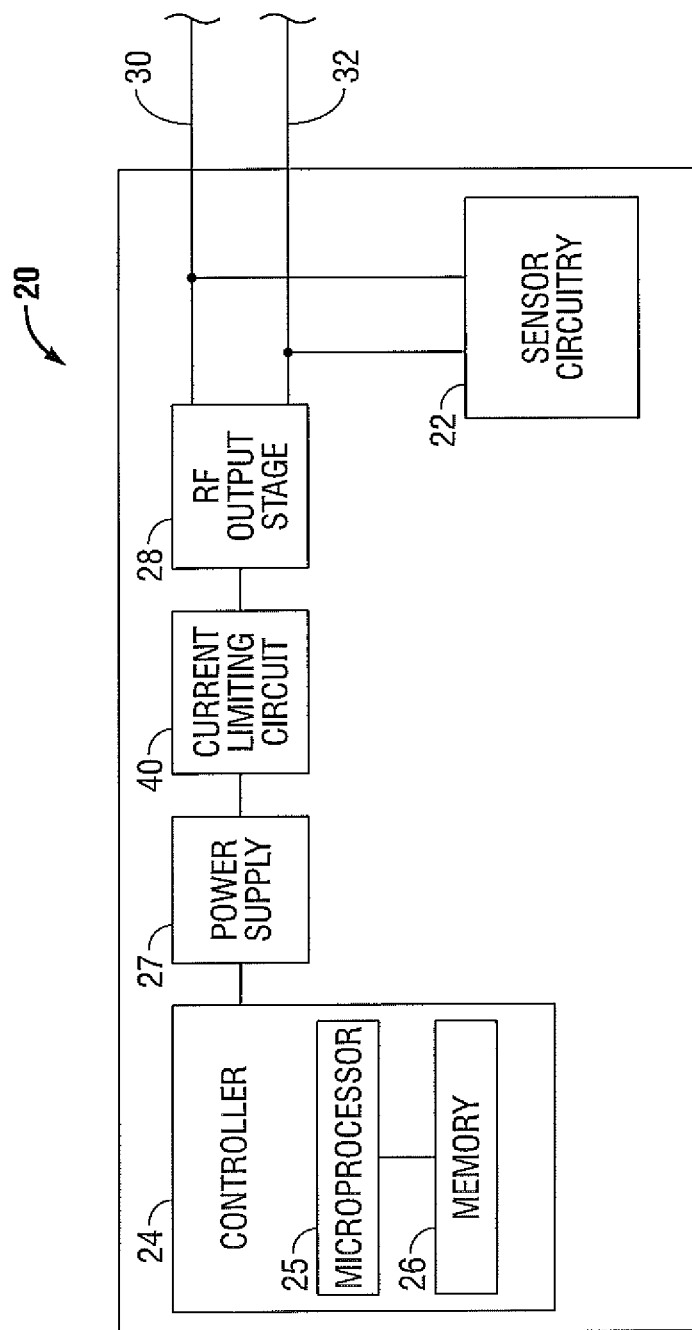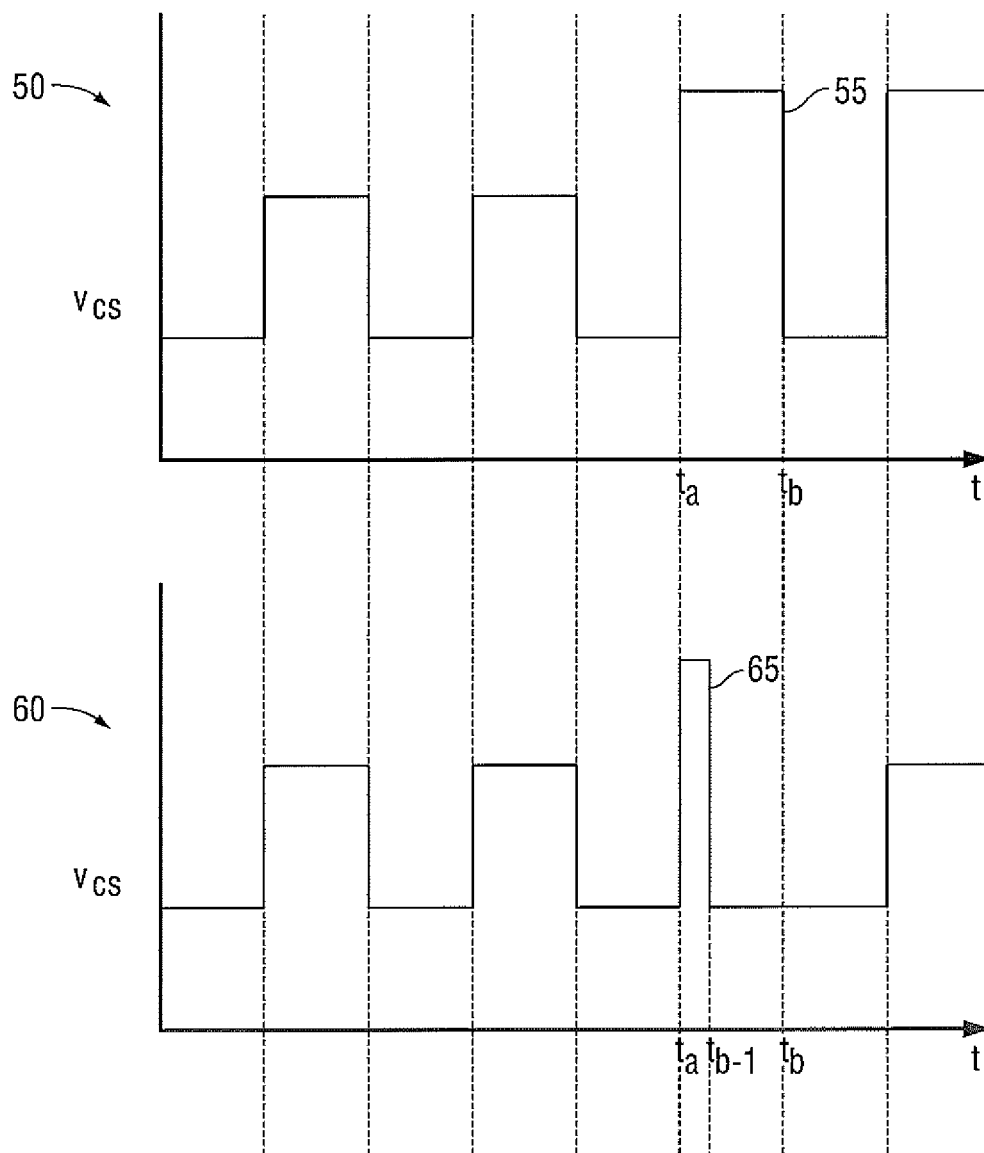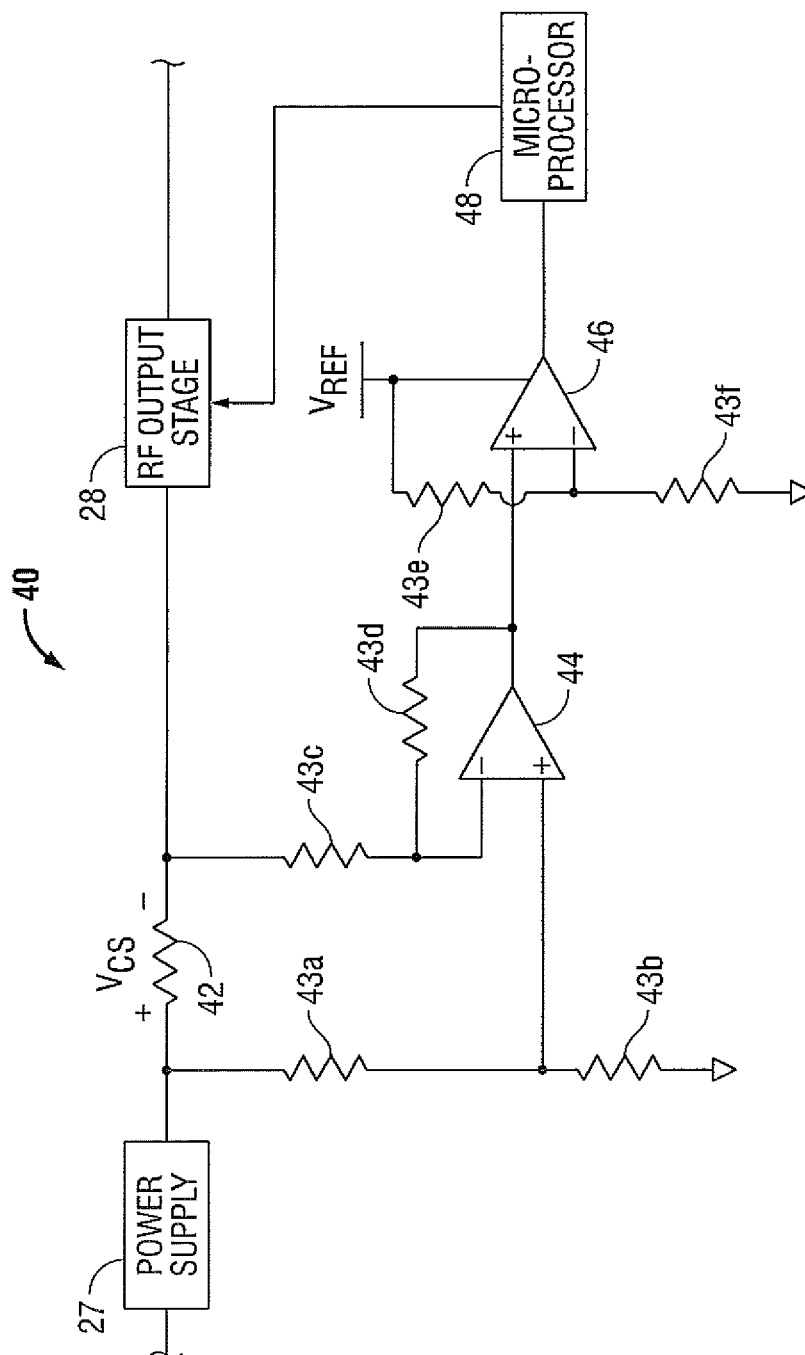
FIG. 2

FIG. 3

FIG. 4

# SYSTEM AND METHOD FOR DETECTING AND SUPPRESSING ARC FORMATION DURING AN ELECTROSURGICAL PROCEDURE

## BACKGROUND

1. Technical Field

The present disclosure relates to an electrosurgical system and method and, more particularly, to arc detection and suppression for electrosurgical tissue treatment procedures such as vessel sealing and tissue ablation.

2. Background of Related Art

Energy-based tissue treatment is well known in the art. Various types of energy (e.g., electrical, ohmic, resistive, ultrasonic, microwave, cryogenic, laser, etc.) are applied to tissue to achieve a desired result. Electrosurgery involves application of high radio frequency electrical current to a surgical site to cut, ablate, coagulate or seal tissue. In monopolar electrosurgery, a source or active electrode delivers radio frequency energy from the electrosurgical generator to the tissue and a return electrode carries the current back to the generator. In bipolar electrosurgery, one of the electrodes of the hand-held instrument functions as the active electrode and the other as the return electrode. The return electrode is placed in close proximity to the active electrode such that an electrical circuit is formed between the two electrodes (e.g., electrosurgical forceps). In this manner, the applied electrical current is limited to the body tissue positioned between the electrodes.

Electrical arc formation is a discharge of current that is formed when a strong current flows through normally non-conductive media such as air (e.g., a gap in a circuit or between two electrodes). Electrical arc formation is problematic when occurring at the site of tissue being treated during an electrosurgical procedure. The arcing results in increased current being drawn from the electrosurgical generator to the electrical arc, thereby increasing the potential of damage to tissue due to the presence of increased levels of current and to the electrosurgical generator due to overcurrent conditions.

## SUMMARY

According to an embodiment of the present disclosure, a method for suppressing arc formation during an electrosurgical tissue treatment procedure includes the steps of supplying pulsed current from an energy source to tissue and measuring the pulsed current supplied from the energy source. The method also includes the steps of comparing an instantaneous measured pulse to a predetermined threshold and controlling the pulsed current supplied from the energy source based on the comparison between the instantaneous measured pulse and the predetermined threshold.

According to another embodiment of the present disclosure, a method for suppressing arc formation during an electrosurgical tissue treatment procedure includes the steps of supplying pulsed current from a current source to tissue and measuring each pulse of the supplied pulsed current. The method also includes the steps of comparing each measured pulse to a predetermined threshold and terminating each measured pulse if the measured pulse exceeds the predetermined threshold.

According to another embodiment of the present disclosure, an electrosurgical system includes an electrosurgical generator adapted to supply pulsed current to an electrosurgical instrument for application to tissue and a current limiting circuit operably coupled to the electrosurgical generator

and configured to measure each pulse of the pulsed current for comparison with a predetermined threshold. Each pulse is controlled based on the comparison.

## BRIEF DESCRIPTION OF THE DRAWINGS

Various embodiments of the present disclosure are described herein with reference to the drawings wherein:

FIG. 1A is a schematic block diagram of a monopolar electrosurgical system in accordance with an embodiment of the present disclosure;

FIG. 1B is a schematic block diagram of a bipolar electrosurgical system in accordance with an embodiment of the present disclosure;

FIG. 2 is a schematic block diagram of a generator in accordance with an embodiment of the present disclosure;

FIG. 3 illustrates a relationship between current source voltage vs. time for tissue undergoing treatment in accordance with two contrasting scenarios; and

FIG. 4 is a circuit diagram of a current limiting circuit according to an embodiment of the present disclosure.

## DETAILED DESCRIPTION

Particular embodiments of the present disclosure are described hereinbelow with reference to the accompanying drawings. In the following description, well-known functions or constructions are not described in detail to avoid obscuring the present disclosure in unnecessary detail.

The generator according to the present disclosure can perform monopolar and bipolar electrosurgical procedures, including vessel sealing procedures. The generator may include a plurality of outputs for interfacing with various electrosurgical instruments (e.g., a monopolar active electrode, return electrode, bipolar electrosurgical forceps, footswitch, etc.). Further, the generator includes electronic circuitry configured for generating radio frequency power specifically suited for various electrosurgical modes (e.g., cutting, blending, division, etc.) and procedures (e.g., monopolar, bipolar, vessel sealing).

Fig. 1A is a schematic illustration of a monopolar electrosurgical system 1 according to one embodiment of the present disclosure. The system 1 includes an electrosurgical instrument 2 (e.g., monopolar) having one or more electrodes for treating tissue of a patient P (e.g., electrosurgical cutting, ablation, etc.). More particularly, electrosurgical RF energy is supplied to the instrument 2 by a generator 20 via a supply line 4, which is connected to an active terminal 30 (see FIG. 2) of the generator 20, allowing the instrument 2 to coagulate, seal, ablate and/or otherwise treat tissue. The energy is returned to the generator 20 through a return electrode 6 via a return line 8 at a return terminal 32 of the generator 20 (see FIG. 2). The active terminal 30 and the return terminal 32 are connectors configured to interface with plugs (not explicitly shown) of the instrument 2 and the return electrode 6, which are disposed at the ends of the supply line 4 and the return line 8, respectively.

FIG. 1B is a schematic illustration of a bipolar electrosurgical system 3 according to the present disclosure. The system 3 includes a bipolar electrosurgical forceps 10 having one or more electrodes for treating tissue of a patient P. The electrosurgical forceps 10 includes opposing jaw members 11 and 13 having an active electrode 14 and a return electrode 16, respectively, disposed therein. The active electrode 14 and the return electrode 16 are connected to the generator 20 through cable 18, which includes the supply and return lines 4, 8 coupled to the active terminal 30 and return terminal 32,

respectively (see FIG. 2). The electrosurgical forceps 10 is coupled to the generator 20 at a connector 21 having connections to the active terminal 30 and return terminal 32 (e.g., pins) via a plug disposed at the end of the cable 18, wherein the plug includes contacts from the supply and return lines 4, 8.

The generator 20 includes suitable input controls (e.g., buttons, activators, switches, touch screen, etc.) for controlling the generator 20. In addition, the generator 20 may include one or more display screens for providing the user with variety of output information (e.g., intensity settings, treatment complete indicators, etc.). The controls allow the user to adjust power of the RF energy, waveform parameters (e.g., crest factor, duty cycle, etc.), and other parameters to achieve the desired waveform suitable for a particular task (e.g., coagulating, tissue sealing, intensity setting, etc.).

FIG. 2 shows a schematic block diagram of the generator 20 having a controller 24, a DC power supply 27, and an RF output stage 28. The power supply 27 is connected to a conventional AC source (e.g., electrical wall outlet) and is adapted to provide high voltage DC power to an RF output stage 28 that converts high voltage DC power into RF energy. RF output stage 28 delivers the RF energy to an active terminal 30. The energy is returned thereto via the return terminal 32.

The generator 20 may include a plurality of connectors to accommodate various types of electrosurgical instruments (e.g., instrument 2, electrosurgical forceps 10, etc.). Further, the generator 20 may be configured to operate in a variety of modes such as ablation, monopolar and bipolar cutting coagulation, etc. The generator 20 may also include a switching mechanism (e.g., relays) to switch the supply of RF energy between the connectors, such that, for example, when the instrument 2 is connected to the generator 20, only the monopolar plug receives RF energy.

The controller 24 includes a microprocessor 25 operably connected to a memory 26, which may be volatile type memory (e.g., RAM) and/or non-volatile type memory (e.g., flash media, disk media, etc.). The microprocessor 25 includes an output port that is operably connected to the power supply 27 and/or RF output stage 28 allowing the microprocessor 25 to control the output of the generator 20 according to either open and/or closed control loop schemes. Those skilled in the art will appreciate that the microprocessor 25 may be substituted by any logic processor (e.g., control circuit) adapted to perform the calculations discussed herein.

A closed loop control scheme or feedback control loop is provided that includes sensor circuitry 22 having one or more sensors for measuring a variety of tissue and energy properties (e.g., tissue impedance, tissue temperature, output current and/or voltage, etc.). The sensor circuitry 22 provides feedback to the controller 24. Such sensors are within the purview of those skilled in the art. The controller 24 then signals the HVPS 27 and/or RF output phase 28 which then adjust DC and/or RF power supply, respectively. The controller 24 also receives input signals from the input controls of the generator 20 or the instrument 10. The controller 24 utilizes the input signals to adjust power outputted by the generator 20 and/or performs other control functions thereon.

In particular, sensor circuitry 22 is adapted to measure tissue impedance. This is accomplished by measuring voltage and current signals and calculating corresponding impedance values as a function thereof at the sensor circuitry 22 and/or at the microprocessor 25. Power and other energy properties may also be calculated based on collected voltage and current signals. The sensed impedance measurements are used as

feedback by the generator 20. In embodiments, sensor circuitry 22 may be operably coupled between RF output stage 28 and active terminal 30.

A current limiting circuit 40 is operably coupled between the power supply 27 and the RF output stage 28 and is configured to instantaneously control the pulsed current output of power supply 27 on a pulse-by-pulse basis. More specifically, the current limiting circuit 40 is configured to monitor the pulsed current output of power supply 27 and, for each output pulse, the current limiting circuit 40 measures the instantaneous current of the pulse and compares the measured instantaneous current to a predetermined threshold current. In some embodiments, the predetermined threshold current may be the maximum allowable current output of the power supply 27. If the measured instantaneous current exceeds the predetermined threshold current, the current limiting circuit 40 controls the pulsed current output of power supply 27 and/or terminates the measured pulse, as will be discussed in further detail below with reference to FIGS. 3 and 4.

In one embodiment, current limiting circuit 40 includes suitable components preconfigured to measure instantaneous current on a pulse-by-pulse basis and control (e.g., adjust, terminate, suspend, etc.) output of generator 20 based on a comparison between the measured current and the predetermined threshold current, as will be discussed in detail below. For example, in some embodiments, the predetermined threshold current may be between about 4.5 A and about 6 A. In another embodiment, the predetermined threshold current may be, for example, data stored in memory 26 and configured to be compared to each current pulse measured by current limiting circuit 40 for processing by microprocessor 25. Based on this comparison, the microcontroller 25 generates a signal to controller 24 to control the pulsed output current of generator 20.

FIG. 3 illustrates the relationship between a current source voltage $v_{cs}$ (e.g., the voltage across power supply 27) vs. time "t" waveform 50, wherein current limiting circuit 40 is not utilized, and a corresponding current voltage source $v_{cs}$ vs. time "t" waveform 60 taken over the same time range as waveform 50, wherein current limiting circuit 40 is utilized in accordance with embodiments described by the present disclosure. Waveforms 50 and 60 illustrate, by way of example, the pulsed output current of generator 20 resulting from the contrasting scenarios discussed above. Waveform 50 is illustrated for purposes of contrast with waveform 60 (described below) to show the benefit of using current limiting circuit 40 to detect and suppress electrical arc formation at the tissue site. Electrical arc formation at the site of the tissue being treated results in increased current being drawn from the generator 20 to the electrical arc, thereby increasing the potential of damage to tissue caused by the presence of increased current and to the generator 20 due to overcurrent conditions.

Waveform 50 illustrates the pulsed output current of RF output stage 28 including an abnormal pulse 55 that represents a significantly increased voltage $v_{cs}$ between time intervals $t_a$ and $t_b$. As described above, the abnormal pulse 55 may be caused by the occurrence of electrical arcing at the tissue site that results in increased current drawn from power supply 27 to the electrical arc and, thus, an increase in voltage $v_{cs}$, for the duration of pulse 55 (e.g., time interval $t_a \leq$ time "t" $\leq$ time interval $t_b$).

Similar to waveform 50, waveform 60 illustrates the pulsed output current of power supply 27 including an abnormal pulse 65 that represents a significantly increased voltage $v_{cs}$ starting at time interval $t_a$ similar to abnormal pulse 55 discussed above. However, in this instance, the abnormal pulse

65 is instantaneously detected by current limiting circuit 40, and terminated at time interval $t_{b-1}$. More specifically, the abnormal pulse 65 is measured and compared to the predetermined threshold current, and terminated at time interval $t_{b-1}$ since the measured pulse exceeds the predetermined threshold current. This is in contrast to the duration of abnormal pulse 55, which without the benefit of detection and termination via current limiting circuit 40 endures from time interval $t_a$ to time interval $t_b$. Since the above described comparison is repeated for each pulse, the current limiting circuit 40 of the present disclosure operates to regulate the duty cycle and, thus, the RMS current of the pulsed current output of the generator 20 to prevent or suppress arc formation, thereby minimizing potential damage to tissue from increased drawing of current to the electrical arc.

Current limiting circuit 40 may include any suitable components to enable operation as described hereinabove such as, for example, current sense resistors, shunt resistors, transistors, diodes, switching components, transformers, and the like. Although shown in the illustrated embodiments as being operably coupled between power supply 27 and RF output stage 28, current limiting circuit 40 may be integrated within power supply 27 or RF output stage 28 or may be operably coupled between RF output stage 28 and active terminal 30.

FIG. 4 shows, by way of example, a circuit schematic of current limiting circuit 40 according to some embodiments of the present disclosure. In this example, current limiting circuit 40 includes a current sense resistor 42 that operates in conjunction with an op-amp 44, a comparator 46, a plurality of resistors 43$a$-$f$, and a microprocessor 48, to control the pulsed current output of power supply 27 that is supplied to instrument 2 or forceps 10 on a pulse-by-pulse basis, as discussed hereinabove.

As power supply 27 supplies pulsed current to RF output stage 28, a potential difference $V_{cs}$ is generated across current sense resistor 42 and received, as input, at the non-inverting or positive input of op-amp 44. $V_{cs}$ is proportional to the pulsed current output of power supply 27. Op-amp 44 generates an output voltage signal that is fed back to the inverting or negative input of op-amp 44 (e.g., negative feedback), causing op-amp 44 to drive its output voltage signal toward a level that minimizes the differential voltage between its positive and negative inputs. The output voltage signal of op-amp 44 is received, as input, at the positive input of comparator 46. A reference voltage $V_{REF}$ (e.g., 3.3 volts) that is proportional to the predetermined threshold current is applied to the negative input of comparator 46 for comparison to the input voltage signal received from op-amp 44. In this way, the pulsed current output of power supply 27 is compared to the predetermined threshold current on a pulse-by-pulse basis by way of comparison, at comparator 46, between $V_{REF}$ and the input voltage signal from op-amp 44. This comparison dictates the output of comparator 46, which will change either from "high" to "low" or from "low" to "high" as the input voltage signal from op-amp 44 exceeds $V_{REF}$. The "high" or "low" output of comparator 46 signals microprocessor 48 to control the output of RF output stage 28 accordingly. As the input voltage signal from op-amp 44 exceeds $V_{REF}$ comparator 46 signals the microprocessor 48 to cause RF output stage 28 to interrupt or terminate the instantaneous current pulse (e.g., pulse 65) being supplied to instrument 2 or forceps 10. For example, in some embodiments, RF output stage 28 includes one or more suitable switching components (not shown) such as a transistor that opens or closes in response to an output signal (e.g., turn-on voltage) received from microprocessor 48. In this scenario, when the switching component is closed, the pulsed current output of power supply 27 is delivered

un-interrupted to instrument 2 or forceps 10 via RF output stage 28 and, when the switching component is open, the pulsed current output of power supply 27 is shunted to ground through resistors 43$a$ and 43$b$ rather than being supplied to instrument 2 or forceps 10. The termination or interruption of an instantaneous current pulse being supplied to instrument 2 or forceps 10 operates to suppress or terminate electrical arcing that may be formed at the tissue site. By terminating the instantaneous current pulse, the voltage $V_{Cs}$ across the current sense resistor 42 decreases below $V_{REF}$ such that the output voltage signal from op-amp 44 is less than $V_{REF}$ by comparison. The resulting output of comparator 46 operates to signal the RF output stage 28 to continue or re-establish (e.g., via closing of the switching component) delivery of pulsed current output from power supply 27 to instrument 2 or forceps 10 for application to tissue. In this way, current limiting circuit 40 controls on a pulse-by-pulse basis whether or not pulsed current is supplied to instrument 2 or forceps 10.

While several embodiments of the disclosure have been shown in the drawings and/or discussed herein, it is not intended that the disclosure be limited thereto, as it is intended that the disclosure be as broad in scope as the art will allow and that the specification be read likewise. Therefore, the above description should not be construed as limiting, but merely as exemplifications of particular embodiments. Those skilled in the art will envision other modifications within the scope and spirit of the claims appended hereto.

What is claimed is:

1. A method for suppressing arc formation during an electrosurgical tissue treatment procedure, comprising:

supplying a plurality of pulses from an energy source to tissue, each pulse of the plurality of pulses configured to be active for a duration of time;

instantaneously measuring each pulse of the plurality of pulses supplied from the energy source;

comparing the instantaneous measurement to a predetermined threshold within the duration of time of each pulse;

reducing the duty cycle of the plurality of pulses supplied from the energy source based on the comparison between the instantaneous measurement and the predetermined threshold; and

terminating each pulse prior to completion of the duration of time based on the comparison between the instantaneous measurement and the predetermined threshold.

2. The method according to claim 1, further comprising terminating each pulse based on the instantaneous measurement exceeding the predetermined threshold.

3. The method according to claim 1, further comprising reducing the duty cycle of the plurality of pulses based on the instantaneous measurement exceeding the predetermined threshold.

4. The method according to claim 1, further comprising using a current limiting circuit operably coupled to the energy source to perform at least one of the measuring, comparing, or reducing.

5. The method according to claim 1, further comprising comparing a first voltage proportional to the predetermined threshold to a second voltage proportional to the plurality of pulses from the energy source.

6. The method according to claim 5, wherein the plurality of pulses are controlled based on the second voltage exceeding the first voltage.

7. The method according to claim 1, further comprising generating a signal based on the comparison between the instantaneous measurement and the predetermined threshold and transmitting the signal to a controller operably coupled to

the energy source, the controller configured to control the duty cycle of the plurality of pulses supplied from the energy source based on the signal.

**8**. The method according to claim **1**, wherein the predetermined threshold is a maximum allowable current output of the energy source.

**9**. A method for suppressing arc formation during an electrosurgical tissue treatment procedure, comprising:

supplying pulsed current from a current source to tissue, each pulse of the supplied pulsed current configured to be active for a duration of time;

measuring each pulse of the supplied pulsed current;

comparing each measured pulse to a first predetermined threshold and a second predetermined threshold during the duration of time;

terminating each measured pulse if the measured pulse exceeds the first predetermined threshold prior to completion of the duration of time; and

reducing a duty cycle of the pulsed current supplied from the current source if the measured pulse exceeds the second predetermined threshold.

**10**. The method according to claim **9**, further comprising using a current limiting circuit operably coupled to the current source to perform at least one of the measuring, comparing, terminating, or reducing.

**11**. The method according to claim **9**, further comprising comparing a first voltage proportional to the first predetermined threshold to a second voltage proportional to the pulsed current from the current source.

**12**. The method according to claim **11**, wherein the pulsed current is terminated based on the second voltage exceeding the first voltage.

**13**. The method according to claim **9**, further comprising generating a signal based on the comparison between each measured pulse and the first predetermined threshold and transmitting the signal to a controller operably coupled to the current source and configured to control the current source based on the signal.

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